

FINAL REPORT

Right Whale Diving and Foraging Behavior in the Southwestern Gulf of Maine

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LONG-TERM GOALS

Mitigation of a variety of anthropogenic threats to endangered baleen whales depends on information about how the whales use the water column. For example, reducing ship strike risk requires an understanding of how much time whales spend at the surface, and mitigating fishing gear entanglements by ground lines requires an understanding of how often and why whales might dive near the bottom. My long-term goal is to characterize baleen whale foraging behavior by studying diving behavior with respect to both the vertical/horizontal distribution of their prey and oceanographic features and conditions (e.g., mixed layer, stratification, turbulence). This approach will allow me to characterize not only where in the water column the whales feed, but also where the prey are located, why the prey are organized as they are, and how the whales respond to variability in prey distribution and oceanographic conditions. By using this same approach to study several baleen whale species, comparisons between species will ultimately be possible to address fundamental questions about foraging ecology (e.g., variability in foraging strategy induced by morphological constraints and/or prey species/behavior) as well as about differential rates of interaction with human activities.

OBJECTIVES

The seriously endangered North Atlantic right whale is particularly vulnerable to ship strikes and fishing gear entanglements, and there is an urgent need for information about how right whales use the water column to develop strategies to mitigate these anthropogenic threats. Moreover, the right whale sits atop a relatively simple food chain consisting only of phytoplankton, copepods, and whales that can serve as a convenient model to study trophic interactions in the marine environment because both predator and prey can be monitored with available technologies (e.g., animal-mounted archival tags, video plankton recorder). From 2004-2010, we conducted research on the diving and foraging behavior of North Atlantic right whales in the southwestern Gulf of Maine (Great South Channel) by attaching tags to the whales, tracking their movements, and simultaneously and repeatedly sampling the water column to measure physical properties (temperature, salinity), biological properties (chlorophyll fluorescence) and prey distribution. In addition to these data, we conducted identical

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tagging/sampling operations in Cape Cod Bay, Stellwagen Bank, Jefferys Ledge, the lower Bay of Fundy, and Roseway Basin. The current study seeks to analyze and publish all of these data in a single paper. Specifically, my objectives are (1) to characterize the diving and foraging behavior of right whales throughout the Gulf of Maine, (2) to investigate the biological and physical oceanographic processes that promote the thin, aggregated layers of copepods upon which the whales feed, and (3) to assess the risks posed to right whales by ships and fishing gear based on their foraging behavior.

APPROACH

Tagging, tracking, and sampling around right whales was accomplished with two vessels: an oceanographic vessel and a small, rigid-hulled inflatable boat (RHIB). Right whales were approached in the RHIB and suction-cup mounted archival tags were attached to the whales using a 9 m pole. The tag consists of a time-depth recorder, pitch and roll sensors, a VHF radio transmitter, and a high-frequency acoustic transmitter. After successful deployment, the tagged whale was actively tracked via a high-frequency acoustic transmitter incorporated in the tag using an acoustic receiver and a hand-held directional hydrophone carried in the tagging boat. The tagging boat remained near the tagged whale at all times to collect identification photographs, behavioral information, fecal samples (if available), and to record the whale's surface locations. Upon resurfacing after each long dive, the whale's exact resurfacing position was recorded by the tagging boat using a global positioning system (GPS) receiver. This position was then relayed via radio to the oceanographic vessel and the ship moved to that position to deploy our vertical profiling instrument package, which consists of a conductivity-temperature-depth (CTD) instrument, chlorophyll fluorometer, optical plankton counter (OPC), and video plankton recorder (VPR). Tracking and sampling with the instrument package continued until the tag detached from the whale, floated to the surface, and was recovered. The tag incorporated a corrosive release mechanism that allowed detachment after 1-3 hours.

WORK COMPLETED

I gave an oral presentation on this work to the North Atlantic Right Whale Consortium Meeting in New Bedford, Massachusetts, November 13-14, 2012. A single paper will be produced from this project; the working title of this paper is "North Atlantic right whale foraging ecology in the Gulf of Maine." Work on this manuscript is nearing completion, and I expect to submit the final version of the manuscript to Marine Ecology Progress Series by December 2013.

RESULTS

Tagging operations took place in 6 regions (Figure 1), but most whales were tagged in just two primary habitats: the Great South Channel and the Bay of Fundy. A total of 113 whales were tagged between 2000 and 2010, but of these, only 55 (49%) had attachment durations greater than 30 minutes. In the Great South Channel, 57 whales were tagged of which 22 (39%) had attachments over 30 minutes, and in the Bay of Fundy, 48 whales were tagged of which 26 (54%) had attachments over 30 minutes. Short attachments were attributable to poor skin condition, variations in tag design, changes in suction cup stiffness, and particularly in the Great South Channel, possible contact with the sea floor. Of the 55 tagging events with attachment durations over 30 minutes, most were between 1 and 2 hours in duration ($n = 33$); average duration was 91 min ($SD = 60$ min), the median duration was 81 min, and the interquartile range was 57-98 min.

Right whales tagged in the Great South Channel exhibited significant variability in diving behavior (Figure 2c,i; Figure 3a). Most tagged whales with attachments over 30 minutes remained at shallow depths: 68% of whales (15 of 22) spent greater than 80% of their time shallower than 20 m (e.g., Figure 3a). Maximum late-stage *Calanus finmarchicus* abundance in the upper 20 m near these shallow-diving whales was very high (OPC: 14,300 copepods m⁻³ on average, SD = 14,300, n = 15 whales, range = 1,890-62,900; VPR: 24,500 copepods m⁻³ on average, SD = 11,800, n = 13, range=1,100-44,800), indicating that the observed periods of shallow diving were primarily associated with feeding. The remaining whales (n = 7) dove repeatedly to depths below 50 m (Figure 3a), spending an average of 46% of their time between 50 m and the sea floor (range = 27–70%). Seven of the 22 whales (32%) dove to within 10 m of the sea floor during the period they were tagged (e.g., Figure 2i), spending an average of 16% of their total time in this depth stratum (range = 3-38%). While some of these dives were V-shaped, characterized by rapid descent and ascent with very little or no time spent in the “at-depth” portion of the dive (hypothesized to be prospecting dives), many dives had similar characteristics to deep feeding dives (i.e., rapid descent, long durations within a narrow depth stratum, and rapid ascent) with the “at-depth” portion of the dive spent near the sea floor.

In contrast, right whale diving and foraging behavior in the Bay of Fundy was considerably less variable than in the Great South Channel (Figure 3c). Right whales consistently dove to mid-water layers of *C. finmarchicus* in the Bay of Fundy; on average, the “at-depth” portion of the dives in the Bay of Fundy occurred at 117.1 m (SD = 22.9, n = 26) and lasted 7.2 min (SD = 3.5, n = 26). In the Great South Channel, the “at-depth” portion of dives occurred at an average 19.7 m (SD = 21.4, n = 22) and lasted only 1.5 min (SD = 1.7, n = 22) (note that this average depth is misleading, since individual whales spent most of their time much shallower or deeper than this average; Figure 3a). Four of the 26 whales tagged in the Bay of Fundy (15%) dove to within 10 m of the sea floor during the period they were tagged, spending only an average of 2% of their total time in this depth stratum (range = 0.6-6%). The majority of these dives were V-shaped.

IMPACT/APPLICATIONS

This work will directly help efforts to mitigate the effects of anthropogenic activities on baleen whales by characterizing where in the water column right whales feed and why the prey are organized as they are. Ultimately, our ability to predict or even forecast right whale distribution will hinge on a fundamental understanding of right whale foraging behavior and how that behavior varies with changes in copepod behavior and distribution.

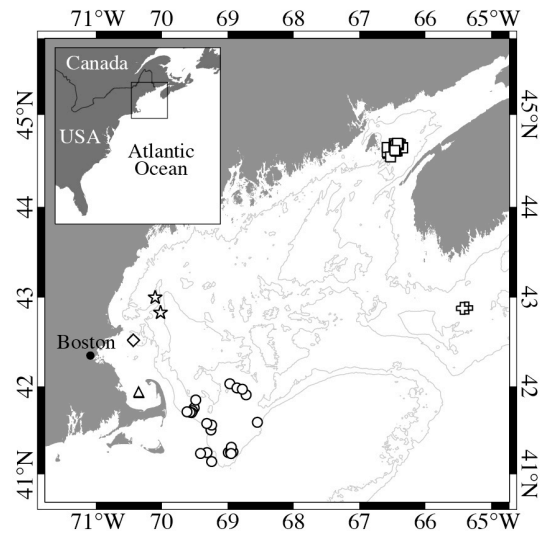


Figure 1. Tagging locations of all whales with tag attachment durations of 30 minutes or more.

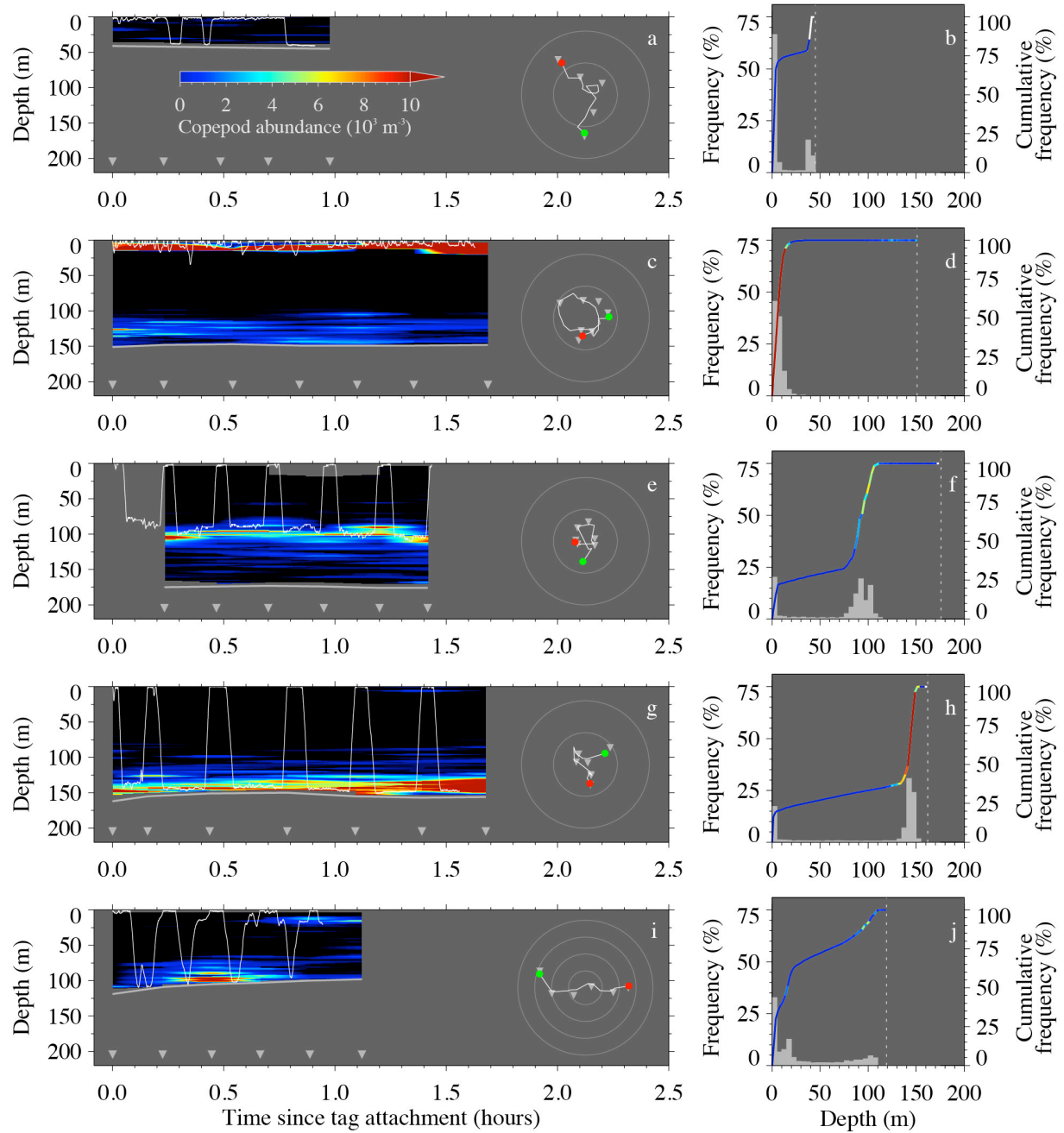


Figure 2. (a,c,e,g,i) Dive data for tagged whales (white line) with collocated late-stage *C. finmarchicus* abundance (colors). Sea floor (thick gray line) and locations of casts with vertical profiling instrument package (inverted gray triangles) shown. Inset indicates movements of tagged whale, including start position (green circle), end position (red circle), and locations of casts (inverted gray triangles). Concentric circles are 1 km apart. (b,d,f,h,j) Corresponding depth frequency (gray bars) and cumulative depth frequency (line) colored with average *C. finmarchicus* abundance. White portion of cumulative depth frequency in (b) indicates no *C. finmarchicus* abundance observations. Dotted line indicates the depth of the sea floor. Whales shown were tagged in (a,b) Cape Cod Bay, 13 March 2006, (c,d) Great South Channel, 30 May 2007, (e,f) Bay of Fundy, 29 August 2001, (g,h) Jefferys Ledge, 11 December 2006, and (i,j) Great South Channel, 25 May 2006.

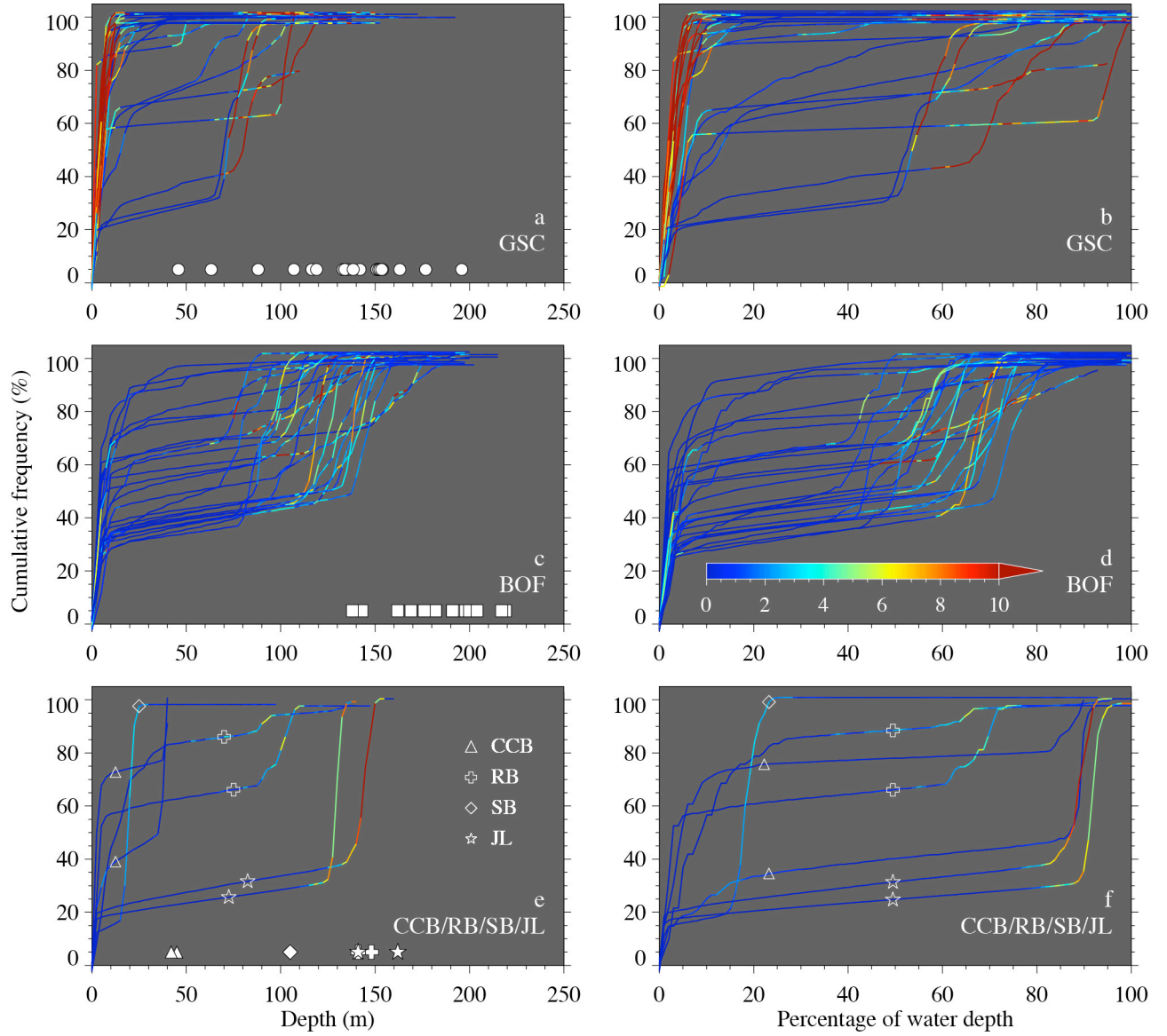


Figure 3. Cumulative distributions of (a,c,e) depth and (b,d,f) percentage of water depth for tagged whales in (a,b) the Great South Channel (GSC), (c,d) Bay of Fundy (BOF), and (e,f) Cape Cod Bay (CCB), Roseway Basin (RB), Stellwagen Bank (SB), and Jefferys Ledge (JL). A random offset between $\pm 2.5\%$ was added to cumulative frequency to distinguish individual whales. Colors indicate abundance of late-stage *Calanus finmarchicus* measured in proximity to tagged whales; color bar in (d) indicates copepod abundance (10^3 copepods m^{-3}). Symbols above x-axis in (a,c,e) indicate water depth for each region, and symbols over each line in (e) and (f) indicate locations of tagging events.